



Supporting Online Material for

Electronic Origin of the Inhomogeneous Pairing Interaction in the High- T_c Superconductor $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$

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This PDF file includes:

SOM Text S1 and S2

Figs. S1 and S2

References

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1. Relationship between the conductance ratio and the boson coupling constant

In the Eliashberg theory of superconductivity, the pairing gap Δ is given by (S1)

$$\Delta = \hbar\omega_c \exp\left(\frac{\lambda - \mu^*}{1 + \lambda}\right) \quad \text{Eq. S1}$$

Here $\hbar\omega_c$ is a cutoff frequency related to the boson density of states, λ is the effective coupling constant and μ^* is the Coulomb pseudopotential. In order to increase the size of the gap and T_c , previous experiments on metallic alloys have focused on either increasing the energy range over which the bosons are coupled to the electrons ($\hbar\omega_c$) or alternatively, increasing the coupling to the bosons λ .

Strong coupling ($\lambda \sim 1$) to a bosonic mode at ω results in structure in the tunneling density of states at an energy $\Delta + \omega$. A change in the energy of the boson shifts the energy scale at which the strong coupling features are observed relative to the gap. On the other hand, increasing the coupling constant does not change the energy at which the features are observed but instead magnifies the size of the strong coupling features seen in the tunneling conductance. In the Lead-Thallium-Bismuth alloys, tuning the percentage of thallium and bismuth in lead does not lead to a significant change in the phonon energies (S2). However, the coupling constant increases monotonically on changing the alloy composition from $\text{Pb}_{0.6}\text{Tl}_{0.4}$ through Pb to $\text{Pb}_{0.65}\text{Bi}_{0.35}$. Such changes in the coupling constant result in a corresponding increase in the magnitude of the strong-coupling features seen in the tunneling conductance (Fig. S1A, from (S2)). It is seen that (Fig. 2B) the RMS value of the deviations from the BCS density of states (over the energy range 0-10 mV) scales with the size of the gap (Fig. S1B). The absence of such scaling for the low-energy boson modes in $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ indicates that the coupling constant is not increasing proportional to the gap size.

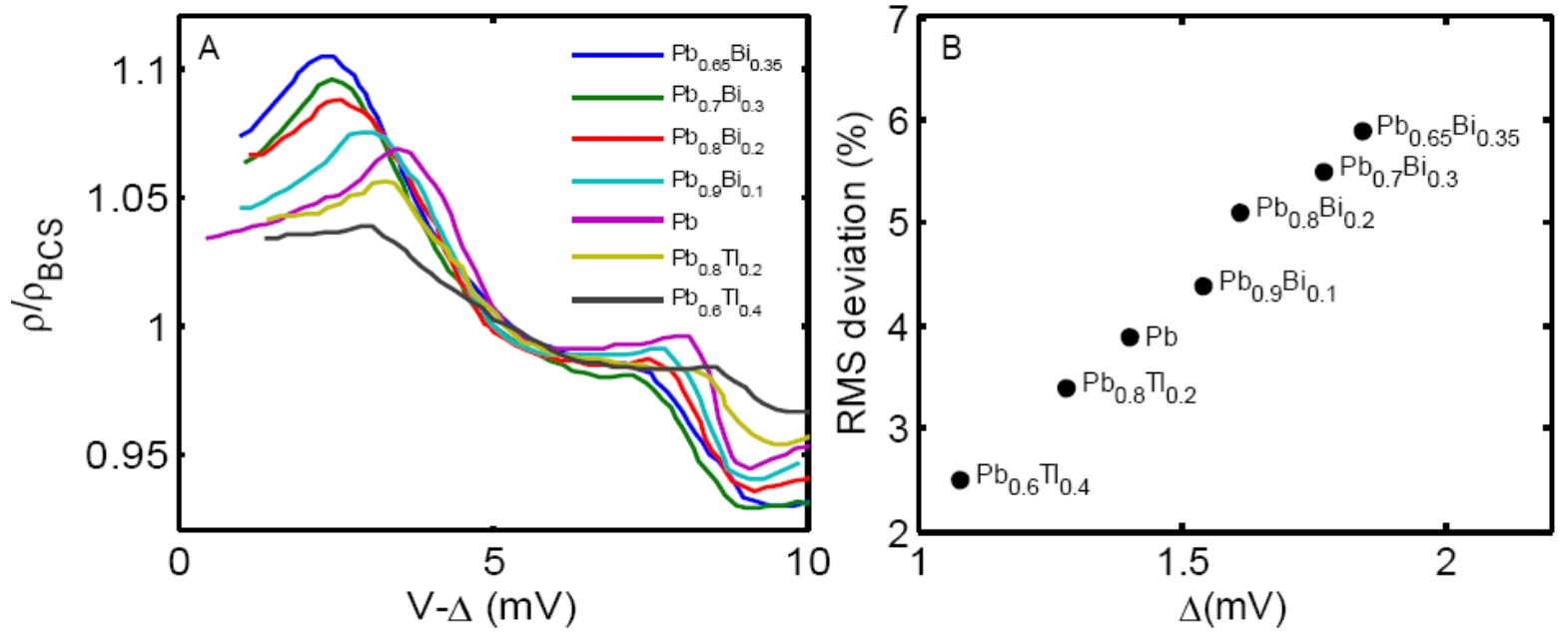
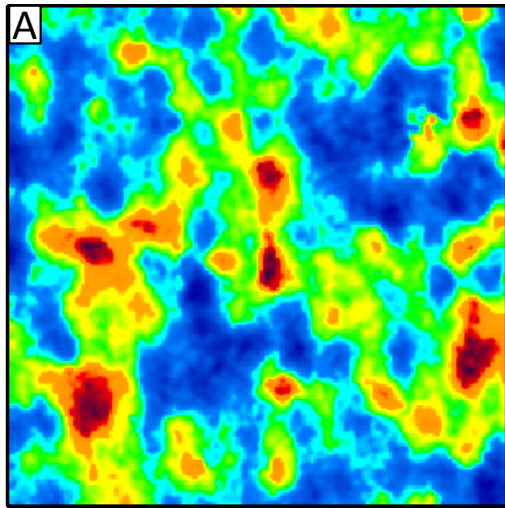


Figure S1: **A.** Strong-coupling deviations from the BCS theory for a series of lead-based alloy superconductors (from *S1*). While the phonon energy does not change significantly across the different materials, the coupling to the phonon increases. This increase causes a corresponding increase in the size of the deviations. **B.** RMS value of the deviations in the energy range 0-10 mV for the different samples in A. As the size of the deviations increases, the value of the superconducting gap also increases.

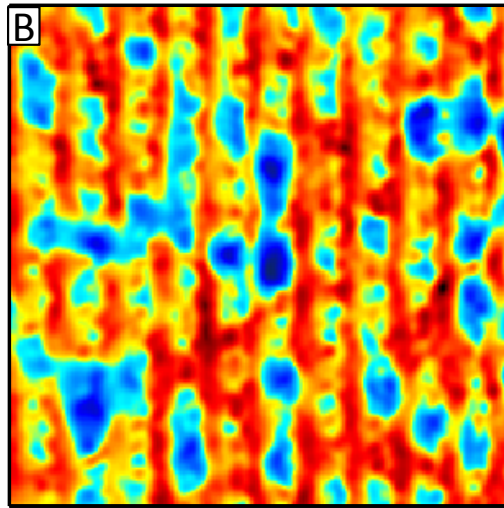
2. Correlation between the normal state, b-axis supermodulation and -900 mV resonances

Previous measurements in the superconducting state of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ (*S3*, *S4*) have shown that the tunneling gap is correlated to inhomogeneity in the structure and electronic properties. In particular, it has been shown that the b-axis supermodulation running through the crystal affects the gap by about 10% (*S3*). It has also been shown that the location of high-energy resonances (previously identified with oxygen dopants) anticorrelates by $\sim 30\%$ with the gap magnitude (*S4*). Our measurements show that these structural and electronic features also affect the normal state spectrum. Shown in Fig. S2A is a gap map of an overdoped $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$ sample ($T_c=62$ K) taken at 50 K. Shown in Fig. S2B is the conductance at the Fermi level measured in the normal state ($T=95$ K). Fig. S2C shows the topograph taken at high positive bias (800 mV) in the same area of the sample showing the b-axis supermodulation. To show the correlation between these quantities, we average these maps along the a-axis. The resultant variation in the gap, normal state conductance as well as the topographic height is shown in Fig. S2E, showing clearly that both the gap as well as the normal state conductance are affected by the b-axis supermodulation.

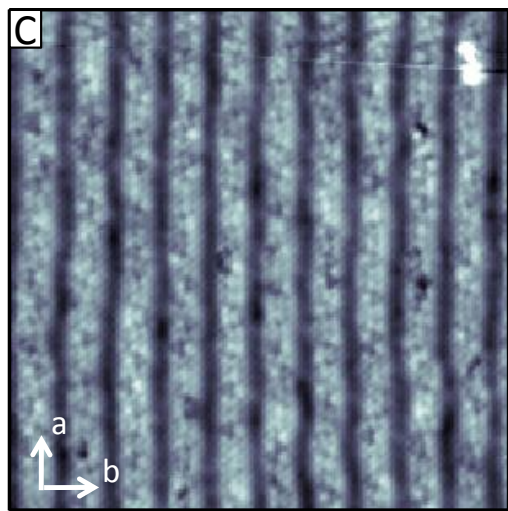
Shown in Fig. S2D is a map of the conductance at -900 meV taken in the normal state showing a number of resonances. These resonances affect both the gap map as well as the normal state conductance as shown in the correlation functions plotted in Fig. S2F. While the resonances have a ~ 30% effect on gap and the normal state, the normal state anticorrelates much more strongly with the gap map as discussed in the text. Our conclusion from such studies is that while a variety of factors can influence the low temperature gap, changes in the gap are foreshadowed by similar changes in the normal state excitation spectrum of $\text{Bi}_2\text{Sr}_2\text{CaCu}_2\text{O}_{8+\delta}$.



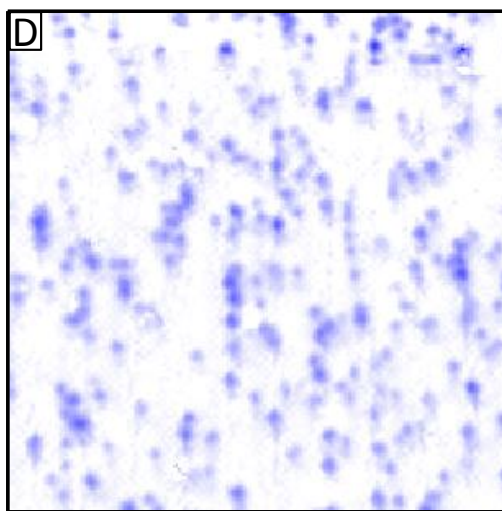
15  40 μV



30  120 pS



-50  50 pm



18  90 pS

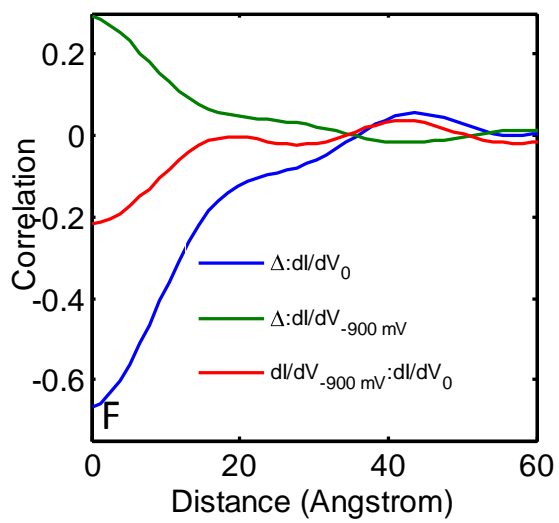
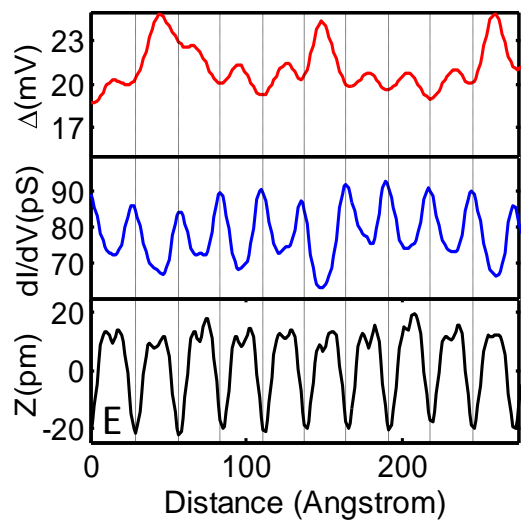


Figure S2: **A.** Gap map of an overdoped ($T_c=62$ K) sample taken at 50 K. **B.** Conductance at the Fermi energy (dI/dV_0) taken in the normal state ($T=95$ K). **C.** Topograph taken at +800 mV sample bias showing the b-axis supermodulation. **D.** Conductance at -900 mV showing resonances scattered in space. **A-D** are acquired in the same area of the sample. **E.** The variation in the gap map, normal state conductance map and topography after averaging along the a-axis. The gap map shows an $\sim 10\%$ change from peak to trough of the supermodulation. **F.** Correlation between the -900 mV resonances and the gap map (green) and between the -900 mV resonances and dI/dV_0 (red). Also shown for comparison (blue) is the correlation between dI/dV_0 and the gap map.

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